Accumulation of Large Foreign Reserves in China: A behavioural perspective

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Abstract

The massive accumulation of foreign reserves by China has challenged the conventional thinking about prudent reserve management. This paper develops a behavioural model of optimal decision making under uncertainty to explain the observed Chinese reserve policy. Departing from the conventional approach to utility maximisation based on the agent's rationality, this paper explicitly models the behaviour of Chinese central banker who is influenced by loss aversion and narrow framing. Embedding the cognitive biases into the precautionary savings approach to holding reserves, the paper shows the behavioural optimality of Chinese reserve build-up and provides a plausible explanation of the dynamics of reserve accumulation in China, hence help make sense of the puzzling Chinese reserve policy.

Keywords: Reserve accumulation; Precautionary savings; Behavioural finance; Loss aversion; Narrow framing.

JEL Classification: C61, F31, F43, G02.

1. Introduction

The accumulation of ever larger foreign reserves by many emerging economies, particularly China, has fundamentally challenged the traditional thinking about sound reserve management. Prior studies have generally articulated a reserve management framework centring on some benchmarks for the appropriate reserve level for a country to hold. Where the reserves are below or above the metrics of the benchmarks, or even a single point of reference, this is commonly considered unhealthy for the economy in question and policy actions are then called for. While in the immediate post-war period it was common for developing economies to suffer from reserve inadequacy, nowadays they tend to hold reserves in excess of the benchmark level. In the case of China, at the end of 2011 the country had accumulated reserves of USD 3181 billion, accounting for 44% of its GDP at the official exchange rate and enough to cover 22 months of imports. This level of reserves far exceeds almost all established criteria for optimal reserves for any country. Yet, the extraordinary reserve build-up is still ongoing in China. Given the fact that excess reserve holdings can incur significant cost, the Chinese reserve policy in recent decades is puzzling. The question then arises: Why is this seemingly irrational stockpiling of reserves tolerated, or even encouraged?

Conventional reserve literature has failed to offer a satisfactory answer to this question. While central banks hold reserves for multiple purposes (Roger, 1993), early studies assume that official reserves chiefly serve to fulfil external obligations (Triffin, 1946). Heller (1966) argues that it is not the transaction motive but rather the precautionary motive that is the main driving force for holding reserves. Frenkel and Jovanovic (1981) suggest that central banks hold reserves as a buffer stock to smooth fluctuations of international payments. These approaches have put forward some benchmarks for optimal reserves based on their respective theoretical underpinning, with varying degrees of success historically. But all of them now fail to explain satisfactorily why, in reality, central banks in recent decades have deviated, often hugely, from the optimal benchmarks (Beck and Weber, 2011).

Many recent studies have attempted either to empirically test or to theoretically explore the motives behind high demand for reserves in the emerging markets (Aizenman and Marion, 2003; Wijnholds and Sondergaard, 2007; Jeanne and Rancière, 2011; Park and Estrada, 2009; Tereanu, 2010; Carroll and Jeanne, 2009; Kim, Shirono, and Dabla-Norris, 2011; Sandri, 2011). Unlike previous studies that focus on achieving a balance between the cost and benefit of holding reserves, the recent literature has turned its attention to the welfare implications of reserve accumulation and to offering an analytical framework based on utility maximisation by rational agents.

One prominent venture in this approach is the development of the precautionary saving model of optimal foreign reserves. The earlier work may be found in Ghosh and Ostry (1997), while recent examples include works by Durdu, Mendoza and Terrones (2009), Jeanne and Rancière, (2011), Carroll and Jeanne (2009), and Sandri (2011). This strand of literature has achieved important advances over previous models. However, like other models using the rationality-based analysis of expected utility, this family of models becomes problematic when applied to the massive accumulation of foreign reserves by emerging countries, particularly China. It remains hard to understand why countries like China would stockpile such a large amount of foreign reserves, which is in stark disagreement with the policy advice offered by this approach.

In all, existing studies have not been very successful in explaining the behaviour of persistent hoarding of reserves in the emerging world.

Motivated by solving the puzzle of China's massive hoarding of foreign reserves, which is seemingly unreasonable from the perspective of conventional economics, this paper seeks to develop an alternative model to current thinking, based on the behavioural approach to optimal decision making under uncertainty as proposed by, among others, Barberis, Huang and Santos (2001). This behavioural model has offered a distinct alternative to rationality-based models for understanding the behaviour of financial markets and policy. In this study, we extend the model to investigate what drives the massive build-up of foreign reserves in China, and the determination of optimal foreign reserves in the context in which decision makers are influenced by cognitive biases.

An analytical model in a behavioural perspective is set up to decode the puzzling development of Chinese reserve stockpiling. Centring on the agent who is cognitively biased when making decisions under uncertainty, the theoretical model embeds the influences of both loss aversion and narrow framing, along with precautionary saving as the main motive for accumulating seemingly large reserves. Then, numerical solution is derived using the Method of Endogenous Grid-points as in Carroll (2006). Benchmark calibration of the model indicates that the precautionary saving motive for foreign reserves becomes much stronger when the agent is loss averse and has the trait of narrow framing. In all possible scenarios under examination, the level of precautionary reserves is higher for the agent with cognitive biases than for the one without. This is also true for the level of optimal precautionary reserves derived from the model.

According to our model, China's actual holdings of foreign reserves are broadly in line with that predicted by the behavioural model. The results highlight China's prudent stance in its foreign reserve policy and complements the current reserve literature by offering a behavioural explanation.

We begin, in Section 2, by reviewing the literature on the motives for reserve accumulation and on the cognitive traits that are commonly found to influence decision making of agents when faced with uncertainty, i.e. loss aversion and narrow framing. In Section 3, after laying down the background of income uncertainty in the Chinese economy and specifying model assumptions, we build a behavioural model incorporating loss aversion and narrow framing. The numerical solution of the model is presented in Section 4, along with the benchmark calibration results and sensitivity tests for the optimal foreign reserves for the agents under the influence of behavioural biases. We draw conclusions in Section 5.

2. Related Literature

2.1. Conventional Thinking on Optimal Reserves

2.1.1. Earlier views

In the context of severe dollar shortage in the period immediately after World War II, Triffin (1946) views foreign reserves as a means of meeting the obligation of external payments, and establishes some benchmarks with regard to a ratio of reserves to imports for judging whether a country has the minimum capability for meeting the obligation. Heller (1966), in the earliest study of the precautionary motive, argues that it is the precautionary purpose, rather than transaction purpose, that mainly drives the demand for accumulating foreign reserves. However, the emphasis of his work is on establishing a framework for cost-benefit analytics.

Frenkel and Jovanovic (1981) suggest that optimal reserves are one that can balance the macroeconomic adjustment costs incurred in the absence of reserves, with the opportunity cost of holding reserves. Assuming a transaction motive, they predict that average reserves hinge negatively upon adjustment cost, the opportunity cost of reserves and exchange rate flexibility, and positively upon GDP and reserve volatility.

2.1.2. The mercantilism motive

In their explanation of the mercantilism motive, Dooley, Folkerts-Landau, and Garber (2004) state that reserve accumulation can be understood as the direct consequence of export-oriented policies implemented by most East Asian countries, particularly China, in order to achieve their aims of creating more jobs and maintaining economic growth through promoting exports. However, Aizenman and Lee (2007) compare the importance of the precautionary motive, i.e. self-insurance against the risk caused by sudden stops, with that of the mercantilism motive, and find that variables related to the precautionary motive are both statistically and economically significant in interpreting reserve accumulation, whereas variables related to the mercantilism motive are statistically significant, but not economically significant, which implies the dominance of the precautionary motive in emerging economies’ reserve demand. For the case of China, Aizenman and Lee (2008) suggest that China’s massive hoarding of reserves takes place under a hybrid of the mercantilism and the precautionary motives.

2.1.3. The precautionary motive

Based on the observation that deeper financial integration has increased developing countries' exposure to short-term capital inflows that are subject to sudden stops and reversals (Edwards, 2004), many recent studies on optimal reserves suggest that reserves can be viewed as self-insurance to mitigate and prevent an undesired output drop or the crisis caused by sudden stops or negative shocks to the economy. This is the precautionary motive.

After Heller (1966), who first points out that the precautionary motive is a dominant influence in monetary authorities' decision to hold international reserves, Ben-Bassat and Gottlieb (1992) generate a precautionary model in which reserves can be used by a borrowing country challenged by default on the external debt. Aizenman and Marion (2003) suggest that following the Asian financial crisis, countries in East Asia began to accumulate massive reserves under the precautionary motive. Aizenman and Lee (2007) show that the reserve accumulation by emerging countries is related to variables that reflect the precautionary motive, and that China is not an obvious outlier. Mendoza's (2010) empirical study suggests that China's reserve holding pattern is driven by the precautionary motive, which is in accordance with other developing countries. Using a more elaborated model, Garcia and Soto (2006) conclude that self-insurance against sudden stops plays an important role in accounting for recent hoarding of international reserves.

Recent studies on optimal reserves interpret the precautionary motive of emerging countries using the consumption-based approach. For example, extending the model by Jeanne (2007), Jeanne and Rancière (2011) quantify the optimal level of reserves from the perspective of consumption smoothing against output drop caused by capital flow volatility. Likewise, Durdu et al. (2009) concentrate on potential sudden stops as a determinant of precautionary foreign asset demand. Carroll and Jeanne (2009) derive a tractable model of the net foreign assets in a small open economy to estimate the optimal level of precautionary wealth against an idiosyncratic risk.

The dynamics of reserve accumulation studied by Obstfeld, Shambaugh, and Taylor (2010) is from a further aspect of macroprudence, which is based on financial stability and financial openness in globalised financial integration. In their model, a central bank needs to accumulate reserves to take the responsibility of lender of last resort and therefore prevent its economy from double drains, i.e. both internal drains (runs from bank deposits to currency) and external drains (flight to foreign currency or banks). Hur and Kondo (2011) develop a small open economy model in which large reserve holdings by emerging economies are an optimal response to an increase in foreign debt rollover risk and therefore can prevent the economies suffering from sudden stops. Calvo, Izquierdo, and Loo-Kung (2012) present a statistical model in which optimal reserves can be viewed as the trade-off between the expected cost of sudden stops and the opportunity cost of holding reserves. Their conclusion indicates that reserves can reduce the probability of sudden stop and its attendant costs.

2.2. Loss Aversion and Narrow Framing

As application of psychology to agents' financial decision making, behavioural finance studies agents' response to financial anomalies (Shefrin, 2009). One critical aspect of this branch of financial study is the agent's preference, in which loss aversion and narrow framing are two main behavioural elements.

Loss aversion is a central proposition of the Prospect Theory (PT) pioneered by Kahneman and Tversky (1979). They propose a value function that is defined over changes in wealth rather than final asset position as in conventional economics. The agents view outcomes either as gains or losses relative to a certain reference point and are more sensitive to losses than to completely commensurate gains; i.e. more weight is assigned to losses than to equally sized gains.

Loss aversion has been well incorporated into finance research. In its effort to provide a new avenue for a better understanding of financial anomalies, the behavioural approach to finance has made important advances one of which concerns the anomaly caused by the disposition effect (Shefrin and Statman, 1985), which is closely related to loss aversion. Shefrin and Statman (1985) show that, under the influence of such an effect, investors tend to sell stocks that have gained value (winners) and to hold on to stocks that have lost value (losers), relative to the stock's purchase price or the reference point. Odean (1998) further shows that investors will sell winners soon and hold losers long.

Some variants of loss aversion have also been applied to explain reserves accumulation (Aizenman, 1998). This is done mainly through the application of Gul's (1991) disappointment aversion. With this effect, Aizenman shows that a stabilisation fund becomes larger than that under expected utility. Aizenman and Marion (2003) further incorporate loss aversion into an inter-temporal consumption model to examine large reserve holdings by Asian emerging markets.

The second important factor influencing individuals' decision-making behaviours is narrow framing, first labelled by Kahneman and Lovallo (1993), whereby they assess a specific risk under a narrow, rather than a broad frame. As suggested by Barberis and Huang (2007), narrow framing indicates that people assess a specific risk in isolation, separately from their other risks. In other words, people act as if they derive utility directly from the outcome of that specific risk, even if the specific risk is just one of many determining their overall wealth risk.

Kahneman and Lovallo (1993) offer a corresponding interpretation for the organisational level. They suggest that for a decision maker facing a series of decisions, whether or not to use a broad frame depends on how her performance will be evaluated and on the frequency of performance. If her performance is assessed narrowly (e.g. when facing a risk, if her performance is estimated on that risk alone), the decision maker frames decisions narrowly. Thus, in the context of the Chinese central bank, it is reasonable for her to assess the risk of GDP growth narrowly, due to the fact that promoting GDP growth is her primary task and her performance is evaluated based on GDP growth.

The effect works only when narrow framing and loss aversion are combined. Since loss aversion only matters for decisions which trigger gains or losses, it would have little impact on decision making where individuals evaluate the specific risk under a broad frame (Read, Loewenstein and Rabin, 1999). Benartzi and Thaler (1995) attribute the equity premium puzzle to myopic loss aversion, which is the combination of narrow framing and loss aversion. Barberis, Huang and Santos (2001) develop a model that incorporates behavioural factors, prominently loss aversion and narrow framing, into the optimal decision-making process. In explaining the equity premium, they show that investors get utility from consumption while facing volatilities in the value of their financial wealth. Loss aversion over these volatilities and narrow framing of risks only in the stock market may help explain the existence of equity premium. Barberis and Huang (2009) further refine the behavioural model of optimal choice uncertainty.

Conventional theories of optimal level and growth of foreign reserves have met increasing challenges in recent years. Relying on the approach in which rational agent maximises expected utility, to derive optimal reserves has proved unsuccessful in shedding light on the huge reserve hoardings in the emerging world, particularly in China. Against this backdrop, incorporating behavioural factors such as loss aversion and narrow framing may prove to be a promising avenue for a better understanding of the rapid accumulation of reserves in China.

3. The Model

To understand China's reserve accumulation behaviour, we first characterise the Chinese growth strategy and the uncertainties surrounding the economic transformation. This sets out the background for delineating assumptions of our model. We then develop a behavioural model of optimal decision making under uncertainty to derive the optimal reserves to explain the Chinese reserve hoarding. Based on Barberis, Huang and Santos (BHS) (2001), this model departs drastically from the conventional consumption-based approach. In what follows, we specify: (A) the approach of BHS (2001); (B) the representative agent's preference informing the maximisation problem; (C) the nature of process generating the resources available to the representative agent, and (D) behavioural factors including loss aversion and narrow framing. In the process, we derive the Euler equations and interpret the precautionary savings motive.

3.1. Model Setup: Background Considerations

3.1.1. The Chinese growth strategy

In December 1978, China launched its first programme of economic reforms, featuring a bold move to establish a market economy, and the focal point of its economic policy started to shift towards promoting economic growth. Since then, the reforms have achieved remarkable progress and maximising growth has been firmly established as China's overwhelming policy goal. In this environment, growth has become the main criterion for measuring policy performance. It is then conceivable that the Chinese policymakers would assess the effects of any uncertainty mainly with regard to GDP growth, and isolate such effects from those on consumption or total wealth. Consequently, along with consumption, maximising GDP growth can and should be incorporated into the preference of Chinese policymakers.

3.1.2. Uncertainties facing the Chinese economy

The past three decades have witnessed remarkable growth in China. Meanwhile, the country has rapidly accumulated massive reserves, particularly since its WTO accession in 2001. However, the Chinese strategy of focusing chiefly on economic growth has given rise to imbalances between the decisive move to a market economy and other supportive measures that would enable the establishment of the market institutions. Consequently, Chinese consumers are faced with formidable uncertainties surrounding the future path of welfare and living standards. Both the fast GDP growth and reserve accumulation are shown in the following Figures.

<Figures 1, 2, about here>

Other crucial reforms, such as those regarding the financial sector and pension schemes, have clearly lagged behind. For example, due to the incompleteness of its financial reform, the Chinese banking system suffers from fragility and the severe problem of non-performing loans. Aizenman and Lee (2008) show that financial fragility in China is largely the outcome of favourable financing provided to the state-owned enterprises (SOE) and to other targeted borrowers. They indicate that non-performing loans (NPLs) were about 23 per cent of GDP on average for 2002-03. Prasad and Wei (2005) also indicate that the underdeveloped Chinese banking system is vulnerable to external shocks because of the reported NPLs problem and the need for a bailout of the banking system. Prasad (2009) suggests that 'loss of confidence in the banking system' is potentially one of the most serious risks facing the Chinese economy. In addition, the underdevelopment of the financial market means that not only workers but also producers in China are exposed to borrowing constraints (Wen, 2009; Wen, 2011; Song et al., 2011). The current pension reform in China generates a negative shock to the completeness of individuals' insurance policies. Chamon et al. (2010) show that China's high household savings are a result of rising income uncertainty and pension reforms. According to them, the permanent uncertainty of household income is stable, while the transitory uncertainty rises sharply.

Furthermore, an economic development strategy that places most weight on the construction of infrastructure has given rise to imbalances in the economic structure itself. Whereas private consumption in China has been squeezed by the inadequate social security coverage, investment has been an overwhelming contributor to growth (Prasad, 2009). In Figure 3, the filled line shows the total amount of private consumption during the last decade, indicating that private consumption is not dominant as a contribution to GDP growth shown by the upper line. Because of the weak private consumption, the Chinese economy is heavily dependent on external demand and so is very vulnerable to external shocks.

<Figure 3 about here>

Such imbalances have made the Chinese economy vulnerable to uninsurable aggregate risks, both internally, through problems such as financial fragility, non-performing loans, and inadequate social security coverage, and externally, through collapse of external demand and shocks of global financial crisis (Prasad, 2009). This means that Chinese policy makers have to take into consideration the possibility of a great downside risk of social and political instability and the consequences thereof, as part of its economic decision process.

3.1.3. GDP growth and foreign reserves

Foreign reserves accumulated by the Chinese central bank can be seen not only as a means of production smoothing, but also as a precautionary defence mechanism, a cushion against the adverse effects on growth when China is hit by negative shocks.

Reserve accumulation can exercise the function of production smoothing for China. Due to inadequacy of the social security provision, the future for Chinese consumers carries great uncertainty. In the meantime, however, financial markets in China are incomplete in that no contingent financial instruments are available to cover such risk. The Chinese accumulation of colossal foreign reserves at the national level can be viewed as a precaution by the authority to guard against possible dire consequences of such uninsured risk. The massive amount of reserves serves to smooth growth fluctuations and hence cushion against the income risk.

In short, the ongoing economic transformation has brought high uncertainty to Chinese consumers. The incompleteness of the financial markets in China means that agents in the Chinese economy lack the instruments to insure against future risks. In this setting, the central bank accumulates foreign reserves as an Arrow-Debru security or a state contingent claim with a view to smoothing consumption on behalf of the whole society. Thus, reserve accumulation by China can be taken as a precautionary measure that serves to provide self-insurance against income risk and to achieve risk sharing within China and across countries.

3.2. Assumptions

For simplicity, we consider a world that consists of two countries: a home country and a foreign country representing the rest of the world. Let the home country be China which is characterised as an open economy with incomplete markets. Further on, we assume the following:

1. In the home country, there is only one agent representing individuals living with an infinite horizon. The agent is the consumer as well as the producer. Time is discrete and indexed by $t = 0,1,2,...$. This sole agent can also be thought of as the central planner (in the form of the central banker) who acts on behalf of the economy. In the context of China, this assumption is reasonable since the Chinese government's overwhelming orientation towards growth targeting has a dominant force driving consumption and production in the country.
2. There is only one sector in the home country. In this sector only tradable goods are produced and consumed by the representative agent. Specifically, home-produced goods

are only for export, and the agent consumes only foreign-produced goods. Because all home-produced goods are for export, output or income is denominated in foreign assets, which can be either consumed or saved. Capital stock accumulation for producing output can be financed by savings in foreign assets, which can be used to smooth both consumption and capital stocks.

3. The representative agent suffers from severe borrowing constraints due to incomplete financial markets. As a result, savings in foreign assets are constrained to be non-negative.
4. The central banker consistently takes steady growth as her main policy object, and sets a target growth rate for the GDP. She also has cognitive biases toward growth, i.e. she is loss averse towards the target GDP growth rate and frames the uncertainty about growth narrowly, i.e. she evaluates this uncertainty by isolating it from consumption or total wealth.
5. Markets are incomplete, so that the number of Arrow–Debreu securities is less than the number of states of nature. This shortage of securities restricts the agent from transferring the desired level of wealth among states and so the central bank will fully bear the risks of growth contraction. It then accumulates foreign assets as a precautionary measure to provide self-insurance against adverse shocks to growth.

3.3. The Behavioural Model of Optimal Reserves

3.3.1. The approach of BHS (2001)

The model developed by Barberis, Huang and Santos (2001) provides a general preference structure in which the representative agent derives utility from two sources. One is the utility in the conventional sense, i.e. the future utility her current wealth will bring from making the consumption decision. The other is related to possible fluctuations of the value of her financial wealth in expectation, which is reflected in her objective function with an extra term.

Inclusion of this additional source of utility allows the model to depart radically from the standard consumption-based approach to decision making. A notable property of this structure is its flexibility to take into account cognitive biases of agents who make decisions under uncertainty. Drawing on a central idea of the prospect theory of Kahneman and Tversky (1979), their model embeds the notion of loss aversion into decision making under risk, hence the utility over fluctuating financial wealth. In addition to loss aversion, it turns out that other well-established ideas in the psychology literature can also be incorporated into the analysis, such as narrow framing (Barberis and Huang, 2009) and the house money effect as uncovered in Thaler and Johnson (1990).

3.3.2. The preference specification

In our model, the central banker as the representative agent in the home country chooses a consumption level C_t and allocates savings, i.e. $M_t - C_t$, between the risk-free asset A_{t+1} and the capital stock I_{t+1} to maximise:

$$E_t \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\rho}}{1-\rho} + \beta B_{t+1} H(\gamma_{t+1}) \right) \qquad (1)$$

In the preference specification (1), the first term in the parenthesis is CRRA utility over consumption C_t. It is a standard feature of the agent's preference in the consumption-based approach. The parameter ρ is the coefficient of relative risk aversion, which controls the curvature of utility over consumption.

The second term in the parenthesis of (1) represents utility from the agent's cognitive biases, as a result of departing from the consumption-based approach. The parameter β is the time discount factor. The scaling factor B_{t+1} is given by:

$$B_{t+1} = B_0 u'(C_{t+1}) = B_0 C_{t+1}^{-\rho} \qquad (2)$$

where $B_0 \geq 0$ indicates the coefficient of narrow framing (hereafter NF), which allows control of the overall importance of utility from the agent's cognitive biases relative to utility from consumption. Narrow framing, first labelled by Kahneman and Lovallo (1993), and extended by Barberis, Huang and Santos (2001) and Barberis and Huang (2009), indicates that the agent evaluates a specific risk or uncertainty by isolating it from consumption or from the total wealth. If $B_0 = 0$, the preference specification (1) is abbreviated to the consumption-based approach with standard utility, if no cognitive biases.

The term $u'(C_{t+1})$ or $C_{t+1}^{-\rho}$, which is the first-order derivative of utility over consumption C_{t+1}, is introduced to ensure that standard utility and cognitive-biases utility are of the same order as aggregate resources increase over time. The term $H(\gamma_{t+1})$ implies that the agent derives utility from fluctuations of growth and is loss averse towards her GDP growth target, using the linear loss aversion function. Barberis, Huang and Santos (2001) and Barberis and Huang (2001, 2009) employ a similar setting to embed cognitive biases such as loss aversion function into their model to characterise the behaviour of the representative agent.

3.3.3. Resources constraints

Under such a preference specification, the representative agent faces the initial given resources M_t, denominated by net foreign assets, available at the beginning of time t. After consumption decision C_t at the beginning of time t, the agent chooses how to allocate her saving, i.e. $M_t - C_t$, between the risk-free asset A_{t+1} and the capital stock I_{t+1} for the output at the end of time t, i.e. at the beginning of time t+1:

$$M_t - C_t = A_{t+1} + I_{t+1} \qquad (3)$$

Due to market incompleteness and inefficiency, the agent is constrained in borrowing, so that she has:

$$A_{t+1} \geq 0 \quad \text{or} \quad M_t \geq C_t + I_{t+1} \qquad (4)$$

As the representative of the producer, the agent is assumed to have a Cobb-Douglas production function with normalised-to-unity labour force:

$$Y_{t+1} = I_{t+1}^{\alpha} \qquad (5)$$

which is an endogenous transitory GDP growth process experienced by the agent, where the term α is the capital share to GDP and $0 < \alpha < 1$.

The agent also experiences a permanent GDP growth process:

$$P_{t+1} = G_{t+1} P_t \qquad (6)$$

where P_{t+1} is permanent GDP growth and G_{t+1} is the permanent GDP growth factor. For simplicity, we assume that $P_{t+1} = P_t$, i.e. $G_{t+1} \equiv 1$, with the consequence that we rule out permanent shocks to income and focus only on the impact of transitory shocks to GDP growth.

We normalise our problem divided by the level of permanent GDP P_{t+1} and use small letters to denote the normalised version of capital letters, such as $m_t = M_t / P_t$, $c_t = C_t / P_t$, and $y_t = Y_t / P_t$. Also, we make the assumption that such ratios are time-invariant. More detailed information on the derivation of the normalised problem can be found in Carroll (2011).

Thus, that the agent faces stochastic transitory GDP growth is captured by adding transitory shocks γ_{t+1} to the Cobb-Douglas production function (5):

$$y_{t+1} = \gamma_{t+1} i_{t+1}^{\alpha} \qquad (7)$$

where γ_{t+1} is log-normally distributed transitory shocks, i.e. $\log \gamma_{t+1} \sim \mathrm{N}\left(-\sigma_\gamma^2 / 2, \sigma_\gamma^2\right)$. This assumption about the distribution of γ guarantees that $\log E[\gamma] = 0$, which means $E[\gamma] = 1$ (the mean value of the transitory shocks is 1).

The transitory shocks γ_{t+1} as the only source of uncertainty to GDP growth indicate the uninsured aggregate shocks that reflect possible internal and/or external risks as described in Section 3.1. The risks threaten to cause recession and financial crisis and hence may lead to dire consequences for growth. The occurrence of the uninsurable aggregate shocks implies that the agent has to fully bear the GDP growth risks, due to the lack of state contingent claims.

In the process of choosing how much savings to allocate between the risk-free asset a_{t+1} and the capital stock i_{t+1}, the agent faces the constraint of market resources m_{t+1} available at the beginning of time t+1 (or at the end of time t):

$$m_{t+1} = R_f a_{t+1} + \gamma_{t+1} i_{t+1}^{\alpha} + (1-\delta) i_{t+1} \qquad (8)$$

where $R_f = 1 + r_f$ is a worldwide risk-free rate factor. The first item on the RHS in equation (8) denotes the amount which earns the risk-free rate r_f after decisions of consumption and capital stock. The item $\gamma_{t+1} i_{t+1}^{\alpha}$ shows the transitory shocks to GDP from exports, and the item $(1-\delta) i_{t+1}$ implies the remaining amount of capital stock after production with a coefficient of capital depreciation δ.

3.3.4. Loss aversion

We embed a behavioural factor showing cognitive biases, i.e. the loss aversion pioneered by Kahneman and Tversky (1979), into the consumption-based model in the spirit of Barberis, Huang and Santos (2001). Carroll (1998) produces a model in which a consumer can obtain utility from the absolute level of wealth adjusted by consumption as well as from consumption, to interpret the phenomenon that rich people have higher lifetime saving rates because they regard the accumulation of wealth as power or social status.

However, even though our representative agent maximises GDP growth, our model is only concerned with the fluctuations of the value of GDP or income around a reference point. Specifically, in our model setting, the central banker derives utility from consumption as well as from fluctuations of economic growth, but she is loss averse towards such fluctuations around a reference point.

The reference point $\bar{y}_{t+1}$ set by the agent is her expectation of transitory GDP growth y_{t+1}. Recalling that $E[\gamma] \equiv 1$, the reference point can therefore be shown as:

$$\bar{y}_{t+1} = E\left[y_{t+1}\right] = i_{t+1}^{\alpha} \qquad (9)$$

We then expound the loss-averse agent by a linear loss aversion piecewise function $H(\gamma_{t+1})$ with the help of Fortin and Hlouskova (2011):

$$H(\gamma_{t+1}) = \begin{cases} \gamma_{t+1} i_{t+1}^{\alpha} & \gamma_{t+1} \geq 1 \\ & \quad \textit{for} \qquad \lambda > 1 \\ \gamma_{t+1} i_{t+1}^{\alpha} + \lambda\left(\gamma_{t+1} i_{t+1}^{\alpha} - i_{t+1}^{\alpha}\right) & 0 < \gamma_{t+1} < 1 \end{cases} \qquad (10)$$

where the term λ is the degree of loss aversion with $\lambda > 1$. If the transitory shock is equal to or greater than 1, i.e. $\gamma_{t+1} \geq 1$, the difference between stochastic transitory GDP growth y_{t+1} and its reference point $\bar{y}_{t+1}$ is equal to or greater than zero, i.e. $\left(\gamma_{t+1} - 1\right) i_{t+1}^{\alpha} \geq 0$, indicating that the expected GDP growth is achieved or over-achieved, hence the utility function is the same as that in standard economics. If $0 < \gamma_{t+1} < 1$, the agent fails to achieve her expected GDP growth and therefore is loss averse, which implies that the resulted utility function is to add the standard one into λ times the difference between y_{t+1} and $\bar{y}_{t+1}$.

3.3.5. Euler equations

In the preference specification (1), the first term in the parenthesis, i.e. CRRA utility over consumption C_t, can be written in the form of Bellman's equation:

$$V(m_t) = \underset{\{c_t, i_{t+1}\}_0^{\infty}}{Max} \left\{u(c_t) + \beta E_t V(m_{t+1})\right\} \qquad (11)$$

subject to

$$m_{t+1} = R_f (m_t - c_t - i_{t+1}) + \gamma_{t+1} i_{t+1}^{\alpha} + (1-\delta) i_{t+1} \qquad (12)$$

In each period, the agent must make two decisions. One is about consumption and the other is how to allocate her saving ($m_t - c_t$) between the risk-free asset a_{t+1} and the capital stock i_{t+1}.

Thus, we now move to derive the first order conditions (FOCs) with respect to both consumption and capital stock.

In standard economics, the FOCs with respect to both consumption and capital stock are derived using the envelope theorem

$$u'(c_t) = R_f \beta E_t \left[u'(c_{t+1}) \right] \qquad (13)$$

and

$$u'(c_t) = \beta E_t \left[\Re_{t+1} u'(c_{t+1}) \right] \qquad (14)$$

respectively, where $\Re_{t+1} = \alpha \gamma_{t+1} i_{t+1}^{\alpha-1} + (1-\delta)$, which is the stochastic return on investing capital stock in GDP growth. Equations (13) and (14) are the typical Euler equations under stochastic GDP growth in the conventional literature.

However, in the context of our model, the central banker has cognitive biases only towards the transitory shock γ_{t+1}, i.e. the uncertainty about GDP growth. Thus, for the loss-averse agent who frames the uncertainty narrowly, the FOCs to consumption and capital stock are

$$u'(c_t) = R_f \beta E_t \left[u'(c_{t+1}) \right] \qquad (15)$$

and

$$u'(c_t) = \beta E_t \left[\Re_{t+1} u'(c_{t+1}) \right] + \beta B_0 E_t \left[u'(c_{t+1}) H(\gamma_{t+1}) \right] \qquad (16)$$

respectively. The second term on the RHS of equation (16) shows the cognitive biases. If $B_0 = 0$, equation (16) is reduced to equation (14). Equations (15) and (16) are the behavioural Euler equations with the stochastic GDP growth from the standard literature being combined with loss aversion and narrow framing.

If the agent faces deterministic GDP growth, i.e. $\gamma \equiv 1$, cognitive biases disappear, i.e. $B_0 = 0$, due to the absence of uncertainty. Thus, the FOCs with respect to consumption and to capital stock become:

$$u'(c_t) = R_f \beta E_t \left[u'(c_{t+1}) \right] \qquad (17)$$

and

$$u'(c_t) = \left(\alpha i_{t+1}^{\alpha-1} + (1-\delta) \right) \beta E_t \left[u'(c_{t+1}) \right] \qquad (18)$$

respectively. The term $\left(\alpha i_{t+1}^{\alpha-1} + (1-\delta) \right)$ is the deterministic return on investing capital stock in GDP growth.

3.3.6. Precautionary savings motive

Precautionary savings can be defined as the extra amount of reserves accumulated by the central bank under uncertainty over the amount accumulated under certainty (Carroll and Kimball, 2008). In conventional economics, precautionary savings are the extra amount of reserves under Euler equation (14) as against the amount under Euler equation (18). If the agent has cognitive biases, precautionary savings can be taken as the extra amount of reserves under Euler equation (16) compared to the amount under Euler equation (18).

4. Numerical Solution

4.1. Solving Numerically for Policy Functions

It is difficult to find a closed form solution using analytical methods, so we resort to numerical method to derive the equilibrium reserve level and the dynamics of the reserve accumulation process. This section describes the procedure of numerical solution for the policy functions of the representative agent. The solving algorithm involves dynamic programming, which defines the information about the current situation needed to make a correct decision as the state and the variables chosen at any given state in time are the control variables. By finding a rule that tells what the control variables should be, given possible values of the state, one derives the optimal plan or the policy function. In other words, a policy function is a rule that determines the control variables as a function of the state.

To help clarify the procedure, we redefine:

$$m_t - c_t = s_{t+1} \qquad (19)$$

and

$$s_{t+1} = a_{t+1} + i_{t+1} \qquad (20)$$

Because the expectation of the Euler equations will depend not only on how much the agent saves, i.e. s_{t+1}, but also on how those savings are allocated between the risk-free asset a_{t+1} and capital stock i_{t+1} with stochastic returns, there are two control variables: c_t and i_{t+1}. The resources m_t are the state variable. The expectation must be defined as a function of the choice of both variables.

Thus, our problem involves two control variables simultaneously, as is implied by the two first order conditions with regard to consumption and to capital stock under uncertainty. Equations (13) and (15) indicate that both standard economics and behavioural economics have the same first order condition (FOC) with regard to consumption, while they have different FOCs to capital stock. Combining equations (13) and (14), the FOC to capital stock in standard economics can be rewritten as

$$R_f \beta E_t\left[u'(c_{t+1})\right] = \beta E_t\left[\Re_{t+1} u'(c_{t+1})\right] \qquad (21)$$

Incorporating equations (15) and (16), the FOC to capital stock in behavioural economics can be written as

$$R_f \beta E_t\left[u'(c_{t+1})\right] = \beta E_t\left[\Re_{t+1} u'(c_{t+1})\right] + \beta B_0 E_t\left[u'(c_{t+1}) H(\gamma_{t+1})\right] \qquad (22)$$

Hence, in standard economics, the two FOCs are (13) and (21) respectively, while in behavioural economics, the two FOCs are (15) and (22).

We can solve this multidimensional optimisation problem by transforming it into a sequence of two simple optimisation problems. First, we evaluate the two optimal levels of asset allocation given the defined grid vector of total savings s_{t+1} on the basis of two different scenarios, i.e. equations (21) and (22), respectively. Second, we approximate the respective consumption decisions, i.e. consumption functions based on these two optimal levels of asset allocation given the same grid vector of s_{t+1}.

Rearranging equations (21) and (22) respectively, we obtain the conditions for optimal asset allocation:

$$\left(R_f - E_t\left(\Re_{t+1}\right)\right) E_t\left[u'(c_{t+1})\right] = 0 \qquad (23)$$

and

$$\left(R_f - E_t\left(\Re_{t+1} + B_0 H(\gamma_{t+1})\right)\right) E_t\left[u'(c_{t+1})\right] = 0 \qquad (24)$$

After defining a grid vector for the total amount of savings, $s_{t+1} = a_{t+1} + i_{t+1}$, we use a numerical root-finder to satisfy these two conditions of asset allocation as in equations (23) and (24), in order that:

$$\left(R_f - E_t\left(\alpha\gamma_{t+1} i^{*\alpha-1}_{t+1} + (1-\delta)\right)\right) E_t\left[u'(c_{t+1})\right] = 0 \qquad (25)$$

and

$$\left(R_f - E_t\left(\left(\alpha\gamma_{t+1} i^{*\alpha-1}_{t+1} + (1-\delta)\right) + B_0 H^*(\gamma_{t+1})\right)\right) E_t\left[u'(c_{t+1})\right] = 0 \qquad (26)$$

respectively. In terms of equations (25) and (26), we can solve for the two pairs of the optimal level of capital stock i^*_{t+1} and risk-free asset a^*_{t+1} respectively, given the chosen grid vector for the end of period total amount of savings s_{t+1}.

Second, with these two pairs of the optimal level of capital stock i^* and the risk-free asset a^* for the corresponding two conditions of asset allocation in hand, rearranging the first order conditions to consumption (13) and (15), we obtain:

$$c_t\left(m_t\right) = \left(\beta R_f E_t\left[c_{t+1}\left(R_f(s_{t+1} - i^*_{t+1}) + \gamma_{t+1} i^{*\alpha}_{t+1} + (1-\delta) i^*_{t+1}\right)^{-\rho}\right]\right)^{-1/\rho} \qquad (27)$$

where $m_t = c_t + s_{t+1}$.

Based on equation (27), the policy function of consumption can be solved by backward iteration until convergence, using the Method of Endogenous Grid-points pioneered by Carroll (2006). We initialise the consumption function of the representative agent at a hypothetical last period in which all the available resources are consumed. Given the defined grid-points of end of period savings $s_{t+1} \geq 0$ (the non-negative savings resulting from the borrowing constraints), using the budget constraints it is straightforward to compute the endogenous grid-points of resources m_t, i.e. $m_t = c_t + s_{t+1}$, consistent with each considered combination of consumption c_t and end of period savings s_{t+1}. By linearly interpolating the pairs (m_t, c_t), we can evaluate the consumption function of the second to last period. Then, we follow the same step for the representative agent to interpolate the consumption function until its convergence.

4.2. The Baseline Calibration

Having analytically explored the determination of reserve accumulation, and in particular the influence of cognitive biases of the decision maker, the model is calibrated to empirically assess the effects of the determinants and the extent to which the behavioural factors affect the dynamics of reserve build-up in China. The calibration results provide the basis for us to estimate the optimal foreign reserve accumulation for China that is in alignment with fundamentals and take into consideration the behavioural influence in decision making under uncertainty. Parameter values in the baseline calibration are chosen based on standard literature such as Carroll and Jeanne (2009) and Valencia (2010). The benchmark calibration will be subject to sensitivity tests later. Table 1 reports the baseline values.

<Table 1 about here>

We use the conventional CRRA utility function $u(C_t) = \frac{(C_t)^{1-\rho}}{1-\rho}$, with $\rho = 2$. The discount factor is set at 0.94 and the world risk-free rate factor is set at 1.04, to guarantee the impatience condition $R_f \beta < 1$. We set the capital share in the production function to be equal to 0.2 and the depreciation rate of capital at 0.1. The degree of loss aversion is set to 2.25, as is typical in the behavioural literature. The effect of narrow framing is set to be $NF = 2$ for the baseline coefficient, implying that the central banker believes that it is twice more important for her to derive utility from GDP growth fluctuations than from consumption. Finally, we show transitory shocks by creating two sequences, i.e. both the values of transitory shocks denoted by γ_{v} and the probabilities of transitory shocks denoted by γ_{prob} to meet $E[\gamma] \equiv 1$.

The numerical solution of the model boils down to finding a time-invariant policy function of consumption as the level of resources $c_t(m_t)$ that determines the representative agent's consumption decision. The baseline consumption functions under both conventional economics and behavioural economics are depicted in Figure 4.

<Figure 4 about here>

In Figure 4, the horizontal axis shows the level of resources m_t, and the vertical axis shows the level of consumption c_t. The dash line is the 45-degree line, implying the borrowing constraint $c = m$. The thin solid line depicts the baseline optimal consumption rule with the conventional rational agent under uncertainty. The thick solid line shows the baseline optimal consumption function under transitory shocks with behavioural economics in which the agent has cognitive biases on GDP growth fluctuations, i.e. the agent are influenced by both loss aversion and narrow framing $(NF = 2)$. At each level of resources m_t, the marginal propensity to consume (MPC) under uncertainty by the agent who is cognitively biased is lower than that under conventional uncertainty. The gap between the two demonstrates that precautionary saving motive is strengthened when incorporating loss aversion and narrow framing into the model.

4.3. Optimal Accumulation of Reserves and Sensitivity Analysis

The calibration results can be interpreted further in the light of the buffer-stock saving behaviour described by Carroll (2011), which sheds light on the determination of optimal accumulation of reserves. According to Carroll (2011), the agent holds assets, i.e. savings, mainly to buffer unpredictable fluctuations of income and therefore to shield her consumption. When facing important income uncertainty the buffer-stock saving behaviour can arise, whereby the agent is both impatient, having desire to spend down her assets or to borrow against future income to finance current consumption, and prudent, which means that, *à la* Kimball (1990), the agent has a precautionary saving motive. Under plausible situations, the tension between her impatient desire to spend down assets and her prudent reluctance to draw down assets too far implies the existence of a target level of wealth (in our context, a target level of reserves). If the actual wealth is below the target level, fear (prudence) will be stronger than impatience and the agent will try to save, while if the actual wealth is above the target level, impatience will dominate over prudence and the agent will reduce her wealth.

Following this exposition, we first derive the target level of resources m_t, based on which we derive the target level of the corresponding risk-free asset a_t as the proxy for the optimal level of reserves. Because of the assumption of one sector in the economy, the amount of imports can be viewed as a proxy for the consumption level. This implies that we can obtain the optimal reserves/imports ratio by dividing the optimal level of reserves by the long-run consumption level. Furthermore, we apply the Hodrick-Prescott filter to the observed imports-to GDP ratio, in order to obtain the ratio of the long-run consumption to GDP. Finally, the optimal reserves to

GDP can be derived by multiplying the optimal reserves/imports ratio by the long-run consumption/GDP ratio.

Following this process, the model calibration results suggest that the baseline optimal ratio of reserves to GDP for the rational agent is 15.46% under standard uncertainty; while, for the agent with cognitive biases, the optimal level of foreign reserves is much higher, reaching 52.40% of GDP when $NF = 2$.

To check the robustness of our model in various plausible scenarios, we conduct sensitivity analyses to examine how the optimal level of reserves changes when parameters change. For simplicity, we report results given variations in the coefficients on narrow framing and the discount factor. The former determines the overall importance of the agent deriving utility from fluctuations of GDP growth, rather than from consumption. The discount factor determines the impatience attribute of the agent. Table 2 below indicates the resulting optimal ratio of reserves to GDP under different values of the two parameters.

<Table 2 about here>

The sensitivity analysis generates sizable variation in the optimal level of reserves. Scaled by GDP, the reserves to GDP ratio varies with changes in the two parameters. For each level of the discount rate, the behavioural factors such as loss aversion and narrow framing consistently bring about optimal reserve levels that are considerably higher than that for the conventional rational agent under uncertainty. It is intuitive that the more the central banker cares about GDP growth, the more she needs reserve assets as a precautionary motive to provide self-insurance against income risk, due to market incompleteness.

5. Conclusions

That China should have persistently accumulated ever larger foreign reserves is perplexing. This paper develops a behavioural model of optimal reserve accumulation to decode the puzzling development. Existing literature has not been very successful in providing a satisfactory explanation for the observed massive build-up of foreign reserves in the emerging world, particularly China. Departing from the conventional reserve literature that relies on rationality of agents, our approach is centred on the agent who is cognitively biased when making decisions under uncertainty. Influences of both loss aversion and narrow framing are embedded into the model of precautionary saving as the main motive for accumulating seemingly large reserves.

Benchmark calibration of the model indicates that taking into consideration agents' cognitive biases is critically important to achieve a better understanding of the stance on international reserves in China. We show that the precautionary motive for reserve accumulation is strengthened when the agent is loss averse and has the trait of narrow framing. In all possible scenarios under examination within the model framework, the levels of precautionary reserves are higher for the agent with these cognitive biases than the one without. According to our model, the actual holdings of foreign reserves by China are broadly in line with the optimal level of precautionary reserves predicted by the behavioural model. The model thus complements the current literature by providing a plausible explanation for the Chinese puzzle of reserve accumulation. The analysis highlights the prudent nature of the Chinese approach to foreign reserve policy, under which the rapid accumulation of massive reserves is an equilibrium response by the Chinese central bank under influence of behavioural biases towards risk and losses.

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Table 1 The Baseline Calibration

Parameter description	Parameter label	Baseline value
Inter-temporal discount factor	β	0.94
The coefficient of risk aversion	ρ	2
World interest rate	Rf	1.04
Capital share of production function	α	0.2
Depreciation rate	δ	0.1
The degree of loss aversion	λ	2.25
The coefficient of narrow framing	NF	2
The values of transitory shocks	γv	{0.9, 1, 1.1}
The probabilities of transitory shocks	γprob	{0.25, 0.5, 0.25}

Table 2 Sensitivity Analysis

	Uncertainty	NF=1	NF=2	NF=5
Beta=0.92	6.59%	19.26%	34.49%	61.21%
Beta=0.94	**15.46%**	30.28%	**52.40%**	90.87%
Beta=0.96	102%	138%	238%	619%

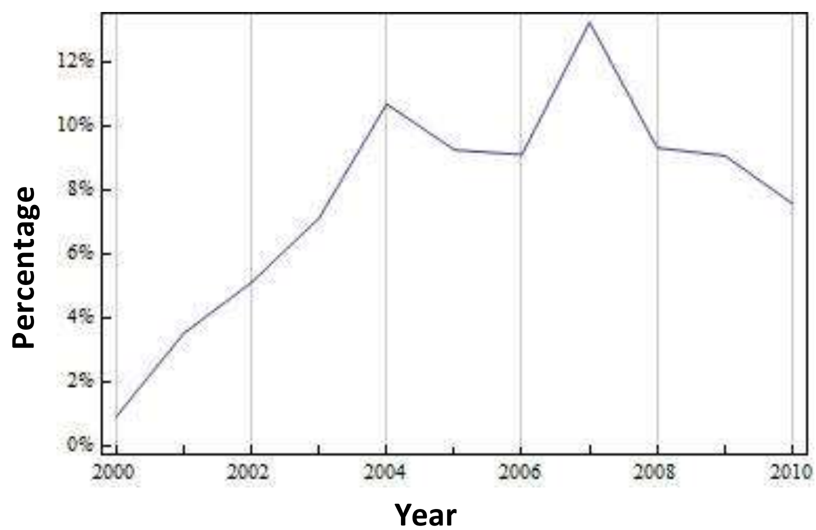

Figure 1 Net Reserves/GDP Ratio

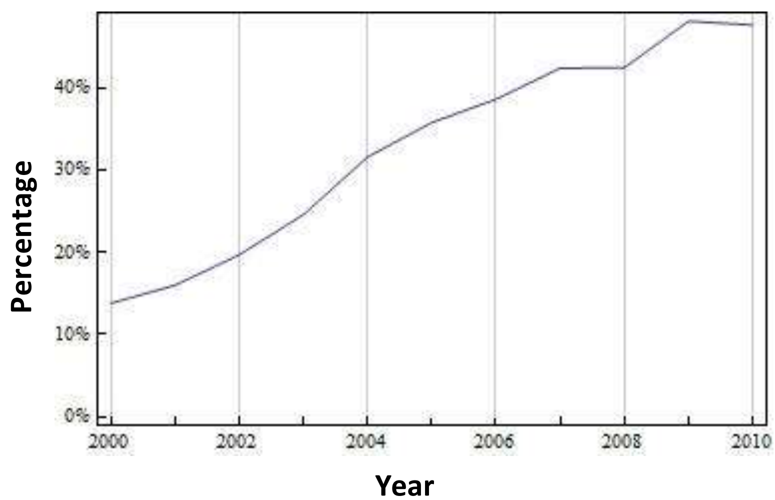

Figure 2 Total Reserves/GDP Ratio

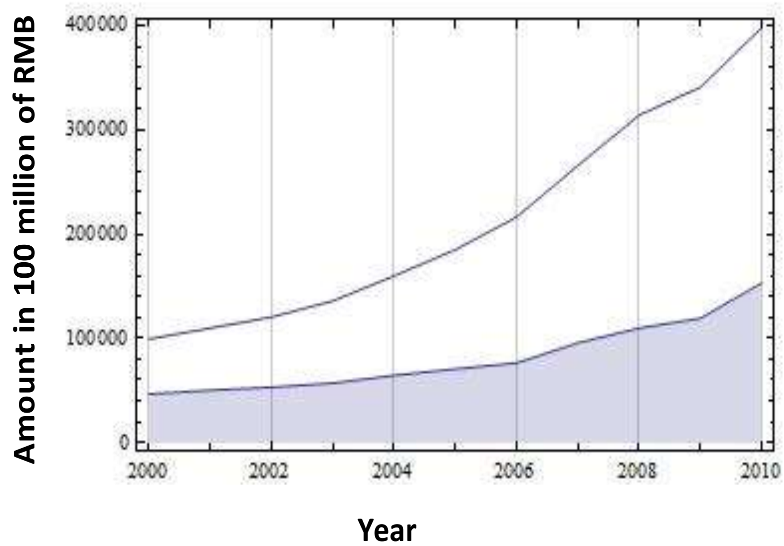

Figure 3 GDP Growth and Private Consumption in China

Note: The upper line: GDP   and the filled line: Consumption

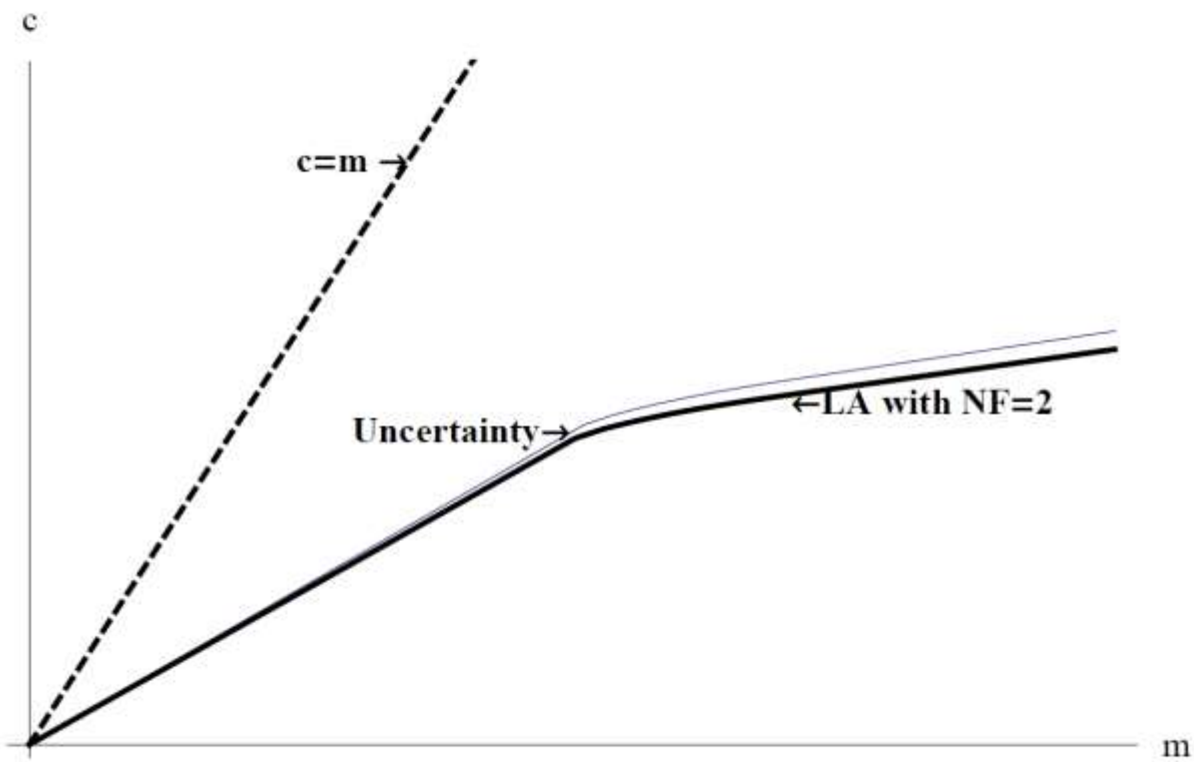

Figure 4 Consumption Functions under Uncertainty vs. LA with NF=2